CPI RF COMPONENTS FOR THE ILC

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Abstract

Communications & Power Industries, Inc. (CPI) has active programs to refine key components for the European XFEL. These components, the fundamental power coupler and the multibeam klystron (MBK) are also suited for the International Linear Collider (ILC). CPI power couplers are manufactured to our customer's specifications using processes which are standard to the electron device industry as well as processes which are specific to power couplers. We have developed the capability of plating high-RRR copper on stainless steel. We have developed the capability of applying TiN coatings to ceramic windows. Both processes are done in-house under carefully controlled conditions. Both processes have been fully qualified. CPI has manufactured over 100 power couplers of various designs. Our presentation will focus on power couplers for the XFEL and the ILC. CPI is currently developing a second-generation, horizontal MBK for DESY. This MBK operates at 10 MW, at an RF frequency of 1.3 GHz, 1.5 ms pulse length, and 10 Hz pulse repetition rate. Our presentation will provide an update on this development program.

POWER COUPLERS

The Beverly Microwave Division of Communications & Power Industries, Inc. (CPI BMD) has been fabricating power couplers for superconducting linear accelerators since 2000 [1]. Table 1 lists the power couplers built at CPI BMD during this time frame.

CPI BMD has fabricated 74 TTF3-type (VWP1137 and VWP3049) power couplers for CNRS-Orsay, DESY, and Fermi Lab. These production programs have involved very close collaboration between CPI, CNRS-Orsay, DESY, Fermi Lab and SLAC. Figure 1 shows the VWP1137 (TTF3) power couplers prior to final assembly.

CPI BMD is an ISO9001:2000 and AS9100 certified organization that designs and manufactures microwave devices and subsystems including solid state components, power supplies, and vacuum electron devices. Our expertise in the design and manufacture of vacuum electron devices is directly applicable to the fabrication of power couplers in both small and large quantities. Vacuum electron devices are very similar in technology and in manufacturing quantities to power couplers. Both involve ceramic to metal seals, joining of dissimilar metals at high temperatures, careful quality control, and require operation at ultrahigh vacuum levels and at very high microwave field levels.

Table 1: CPI Power Couplers

CPI Model Number	Accelerator Application	Freq. (MHz)	Peak and Average Power (kW)	No. Built to Date
VWP1133	SNS Prototype (AMAC, JLAB)	805	1000 and 60	6
VWP1162	RIA Prototype (MSU)	805	1000 and 10	2
VWP1137 and VWP3049 (TTF3)	Tesla Test Facility (CNRS Orsay, DESY) and ILC Test Area (Fermi, SLAC)	1300	1100 and 7.2	74
VWP1136	Tesla Test Facility (AMAC)	1300	1100 and 7.2	2
VWP3032	ERL Injector (Cornell)	1300	75 and 75	12
VWP1185/86	FEL Injector (AES, JLAB)	748	350 and 350	4
VWP3038	Third Harmonic Cavity (Fermi)	3900	45 and 12.5	6
VWP3069	ERL Injector (Daresbury) [2]	1300	75 and 75	2
VWP3070	FEL Injector (AES, BNL) [3]	748	1000 and 1000	2 (in prod.)

Figure 1: VWP1137 (TTF3) power couplers prior to final assembly.

Manufacturing Processes Developed at CPI for Power Couplers

We have developed a high-RRR electroplating process for copper on stainless steel as well as a process to deposit an anti-multipactor TiN coating on surfaces.

The high RRR copper-plating process is an electroplating process. For the qualification process, copper-plated stainless steel strips were provided as samples to CNRS-Orsay. Through a series of process improvements, the RRR of the plated copper is in the range of 30-80, meeting the current specifications. Values of RRR over 200 have been demonstrated.

We chose to replicate the TiN coating process developed at DESY. The TiN coating process involves the deposition of thin TiN films on alumina ceramics in a reactive ammonia atmosphere. TiN-coated copper test samples were provided to DESY. The multipacting behavior of these samples were measured at DESY [1]. Figure 2 shows the results of these tests. Sample 1 is an uncoated copper sample. Sample 2, with reduced multipacting duration, is an as-received TiN-coated sample. Sample 3, with further reduced multipacting duration, was done after the TiN-coated sample was cleaned, dried, and baked out. These measurements prove that the TiN coating composition and thickness are sufficient to suppress multipacting.

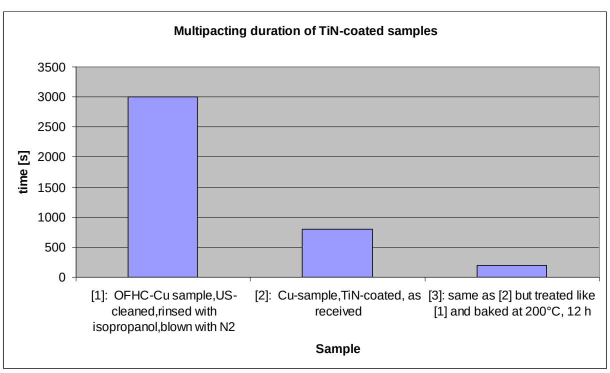

Figure 2: Results of DESY measurements on CPI samples showing multipacting duration of TiN-coated samples. Data provided by Arne Brinkmann of DESY.

A number of manufacturing improvements have been introduced during this year's production of 42 power couplers. Manufacturing processes have been revised to improve surface finish, workmanship, and overall quality. An extensive photographic inspection process has been introduced at our facility to address and record performance to qualitative and quantitative specification requirements. These quality control processes have been developed in collaboration with DESY and CNRS-Orsay.

Highlights of ILC Cost Study – Power Couplers

In 2007, CPI, AES and Meyer Tool and Mfg. Co. performed a cost study for Fermilab of RF Units for the ILC [4]. A single RF Unit is comprised of 3 cryomodules in series powered by a single RF power system. A single RF Unit contains 24 power couplers. CPI BMD performed the power coupler cost study using the XFEL coupler, as specified in the GDE's RDR. As part of this cost study, we provided an estimate for the fabrication, cleaning, assembly, and conditioning of 24, 6000 and 18,000 power couplers. In support of the XFEL, we also estimated costs for 1000 power couplers.

Fabrication cost estimates were based upon our experience building TTF3 power couplers. Labor hours were estimated for each assembly step based on engineering estimates and history. Material costs constituted 45% of the total cost. Labor and overhead constituted 50% of the total fabrication cost. Fabrication equipment procurement costs made up the remaining 5% of the total cost of fabricating 6000 power couplers. Assembly labor made up 83% of the total labor to fabricate the couplers.

We estimated the cost to clean and assemble and condition the fabricated power couplers based upon published data from CNRS-Orsay. To date, industry has only fabricated power couplers with clean-room assembly and conditioning occurring entirely at national laboratories. In our cost study, a 90% learning curve was assumed as was 20 hours of average conditioning time. The overall cost to clean and assemble and condition 6000 power couplers was 26% of the total cost of power couplers. Our cost study included the cost of all capital equipment required to clean and assemble and condition the power couplers at our facility.

MULTIBEAM KLYSTRON

CPI's second generation, 10 MW, 1300 MHz multiple beam klystron (MBK), designated the VKL-8301B, has been developed and is being built for the European X-ray Free Electron LASER (XFEL) [1], which is under construction at DESY in Hamburg (Germany). At 10 MW peak rf output the MBK is required to provide at least 65% efficiency and more than 3 MHz instantaneous –1dB bandwidth. Average power and rf pulse length are 150 kW and 1.5 ms, respectively. Further operating parameters are listed in table 2. This design also satisfies the baseline requirements for the International Linear Collider (ILC) as established by the ILC Global Design Effort members in the ILC Reference Design Report.

MBKs have the advantage of generating high rf output powers at moderate electron beam energies. For our design, six off-axis electron beams enable low cathode current density for long cathode life. The baseline beam optics design was created using our in-house 2.5D code XGun. With state-of-the-art 3D modeling software for beam optics (MICHELLE) and magnetics (MagNet) we then validated and optimized the design for reduced beam scallop and to control the beam position within the beam tunnel. At the same time the gun was designed to reduce voltage gradients for reliable operation. The gun was modeled using the commercially available software ElecNet, which showed maximum voltage gradients as low as 60 kV/cm.

Table 2: Operating and Performance Parameters of the VKL-8301B Multibeam Klystron.

Peak Power Output	10 MW (minimum)
Ave. Power Output	150 kW (minimum)
RF Pulse Length	1.5 ms
Beam Voltage	115 kV (typical)
Beam Current	133 A (typical)
Efficiency	65 % (minimum)
Frequency	1.300 GHz
-1dB Bandwidth	>3.0 MHz
Saturated Gain	51 dB (typical)
Number of Beams	6
Number of Cavities	7 coax., fund., harmonic
Focusing	CFF (electromagnet)
Cathode loading	<2.25 A/cm2 (typical)
Solenoid Power	<5.5 kW

Compared to our first-generation design, where higher-order-mode cylindrical cavities were used [6], we are utilizing coaxial cavities operating in the fundamental-mode. For the cavity design we utilized the commercially available 3D codes MAFIA and HFSS. The use of fundamental-mode ring-resonators ensures sufficient beam separation while still keeping the overall diameter of the device small in order to reduce cost. For its intended use in the XFEL series production, the klystron is horizontally oriented and features a gun oil tank adapter, coaxial gun contacts to connect to a spring-loaded socket, a cart with klystron position alignment and integrated X-ray shielding.

Our in-house 1D large-signal rf code (LSCEX) was used to generate the initial rf design. NRL/SAIC's 2.5D rf code TESLA enabled us to verify and refine the design. The expected frequency response simulated for one electron beam is shown in Figure 3. The expected rf output power versus drive power for one beam is shown in Figure 4. The simulations indicate that the RF design will exceed the required performance and provide stable operation.

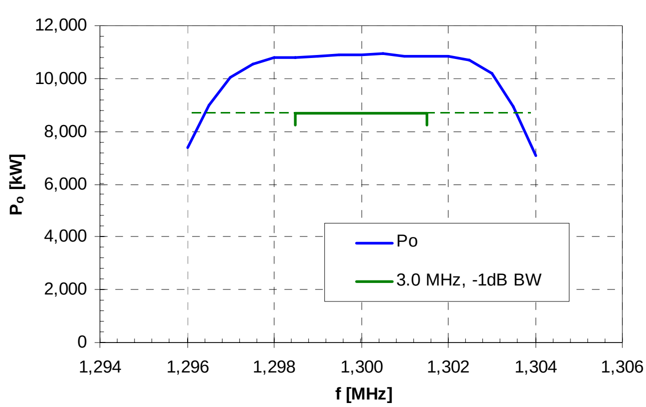

Figure 3: VKL-8301B, frequency response simulated using TESLA at 12.8 W drive power.

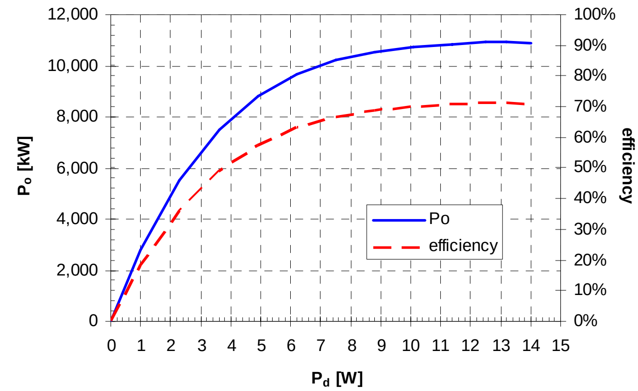

Figure 4: VKL-8301B at 1300 MHz, transfer curve simulated using TESLA

CPI is currently in the process of building the horizontal klystron prototype. Testing is scheduled for the late summer 2008.

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